# Glimpse of heavy electrons reveals “hidden order”

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## *Researchers unravel 25-year-old physics mystery*

LOS ALAMOS, New Mexico, June 3, 2010—Unconventional use of a well-known scientific instrument has helped scientists from Los Alamos National Laboratory, Brookhaven National Laboratory, and other institutions unravel a 25-year-old physics mystery and reveal a “hidden order” of the electronic structure inside an unusual superconducting material.

In a paper released today in Nature, Alexander Balatsky of Los Alamos’ Theoretical Division, Séamus Davis of Brookhaven National Laboratory, and Graeme Luke of McMaster University (Ontario, Canada) describe the use of spectroscopic imaging scanning tunneling microscopy to view the “hidden order” of electrons within uranium ruthenium silicate as it is cooled to very low temperatures. The research could lead to engineered materials that exhibit superconductivity by helping physicists better understand the behavior of heavy fermion materials—exotic compounds whose slow-moving electrons behave as if they have a mass 1,000 times greater than ordinary free electrons.

Since 1984, just prior to the cusp of discovery of high-temperature superconducting materials, scientists studying the behavior of heavy fermion materials noticed that as the superconducting material uranium ruthenium silicate was cooled to temperatures below 55 degrees Kelvin (minus 360 degrees Fahrenheit), its specific heat increased.

In simple terms, specific heat is a measure of the amount of energy (heat) required to raise the temperature of a material; the increase in specific heat showed that for some reason the material was absorbing more energy than at room temperature. Some physicists theorized that perhaps the energy was needed to maintain some type of unusual or unseen order of the material’s atomic lattice.

At 17.5 Kelvin (minus 428 Fahrenheit), the specific heat increase was far greater than any measured magnetization would suggest, presenting researchers a materials mystery.

“For 25 years there was this idea that there was some kind of hidden order of electrons occurring within these materials at lower temperatures,” said Balatsky. “It was like having a pebble in your shoe. You know something is there, but you can’t see it. It becomes so maddening that eventually you have to take off your shoe and take a really good look.”

Fortunately for physicists, a modern spectroscopic technique called scanning tunneling microscopy provided the right tools for a look inside the analogous shoe.

Balatsky and colleagues pioneered a way to use the spectroscopic imaging scanning tunneling microscope (SI-STM) to look at the structure of the heavy fermion material as it cooled. The microscopic probe scans an area just above the surface of a tiny grain of material. Small changes in the electronic structure are detected by the apparatus as the probe dances above the surface of the material. The result is somewhat like a topographic map of the material's electronic structure, showing peaks and valleys of areas dense with electrons or barren of charge.

As the material cooled below 55 Kelvin, the SI-STM revealed the appearance of "heavy" electrons. Because of the relationship between kinetic energy and mass, slower electrons appear heavier than freely moving electrons. At 17.5 Kelvin, the topographical map created by the SI-STM revealed a specific, clearly recognizable pattern—a previously hidden order—that is seen as an onset of additional dramatic slowing of electron waves due to interference with uranium atoms within the material. Scientists could finally see the pebble in the shoe.

The remarkable breakthrough helps validate theory behind the observed increase in specific heat of the material. More important, researchers have now confirmed the ability to directly visualize atomic interactions that are responsible for fermion "heaviness" in these materials. This ability could allow researchers to engineer materials with specific superconducting properties or other desirable attributes and directly observe the electronic interactions within them. Ongoing theoretical modeling at Los Alamos of hidden order is a viable tool in this quest for new material properties.

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